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ABSTRACT

The chloride ingress into concrete under water pressures of 100 kPa and 800 kPa have been investigated by experiments. The specimens were exposed to a 10% NaCl solution and water mixture. For the concrete having $w/c = 0.35$ the experimental results show the chloride diffusion coefficient at 800 kPa (~ 8 atm.) is 12 times greater than at 100 kPa (~ 1 atm.). For $w/c = 0.45$ and $w/c = 0.55$ the chloride diffusion coefficients are 7 and 3 times greater. This means that a change in pressure highly influences the chloride ingress into the concrete and thereby the life length models for concrete structures.

Key words: Concrete, w/c -ratios, water pressure, chloride diffusion coefficient

1. INTRODUCTION

It is important to be aware of the chloride concentration inside concrete structures. If the chloride concentration at the reinforcement reaches a critical level it will start to corrode. This will reduce or influence the durability of the concrete structure.

Large constructions such as tunnel elements and foundations for bridges can be placed on large sea water depths where the water pressure is fairly different from the pressure in the splash zone. When the life length for such a concrete structure on a large sea water depth is estimated using the normally used models, the concrete test specimens is typically exposed to sea water at atmospheric pressure, i.e. 100 kPa, which corresponds to the pressure in the splash zone. Therefore chloride ingress into concrete under water pressures of 100 kPa and 800 kPa is investigated to see if there is a significant difference in the obtained chloride diffusion coefficient [1].

2. METHODS

2.1. Types of concrete

The chloride ingress experiments were conducted on concretes with three different w/c-ratios – 0.35, 0.45 and 0.55. All concretes were cast without additives (pure Portland cement (CEM I)) to avoid any influence of these. However, a superplasticizer was used to cast concrete with w/c = 0.35 to improve the workability. By choosing the above mentioned w/c-ratios, the experiments were conducted on concretes with almost the same maturity (~30 days). The concrete with w/c = 0.35 is self desiccating whereas the concretes with w/c = 0.45 and 0.55, respectively, contain excess water. Concrete with w/c = 0.55 has such a high capillary porosity that the chlorides are expected easily to penetrate into this concrete. For comparison the experiments were also conducted on the actual concrete mix from the Great Belt Tunnel in Denmark. This concrete has a w/c-ratio of approximately 0.35 and contains puzzolans (fly ash and microsilica).

2.2 Experimental procedure

The experiments were conducted at a pressure of 100 kPa (~1 atm.) and 800 kPa (~8 atm.). A pressure of 100 kPa corresponds to the pressure in the splash zone. A pressure of 800 kPa corresponds to the water pressure that concrete structures on large depths (80 meters = theoretical depth of the tunnel under Great Belt) are exposed to.

All of the experiments have been made on cylindrical concrete specimens with a height of 8 cm and a diameter of 10 cm. The curved sides of the specimens were painted with epoxy resin so that the chloride ingress could only take place through the top or the bottom of the cylinders. Before exposure of salt water all specimens were dried at 40 °C in 5 days. The specimens were exposed to a 10% NaCl¹ solution and were submerged into the salt solution through the experiments. At 100 kPa the specimens were exposed to salt water for 23 days. At 800 kPa the time for exposure depended on the w/c-ratio. Specimens at w/c = 0.35 were exposed for 1 day and specimens at w/c = 0.45 and w/c = 0.55 for 5 days. Figure 1 shows the water pressure equipment used for the experiments at 800 kPa.



Figure 1 – The water pressure equipment at Rambøll Danmark A/S.

¹ 10 % NaCl solution is used in other accelerated chloride diffusion test such as NT Build 492 [2]

After exposure of salt water the amount of chlorides in the concrete were measured by means of titration on powder samples.

3. RESULTS AND DISCUSSION

The measured chloride content through the specimens made it possible to draw chloride profiles of the chloride variation through each specimen. Hereby the chloride diffusion coefficient was estimated by using the Error Function solution to Fick's 2. Law of Diffusion. Figure 2 shows an example of the chloride profile for concrete with $w/c = 0.35$ used to estimate the chloride diffusion coefficient.

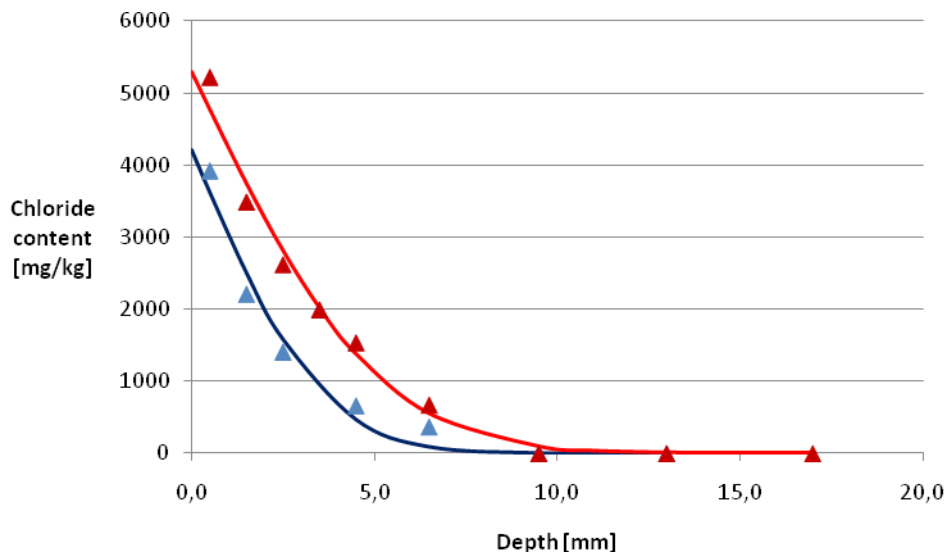


Figure 2 – Chloride profile of concrete with $w/c = 0.35$ at 100 kPa (red) and 800 kPa (blue). Measurement results are marked.

From Figure 2 it is seen that the Error Function solution to Fick's 2. Law of Diffusion fits the experimental data fairly good and therefore the chloride diffusion coefficient can be estimated by using the Error Function solution.

Table 1 summarizes the chloride diffusion coefficients for the different concretes.

Table 1 – Chloride diffusion coefficients for concretes with different w/c -ratios at different pressures. * = Values are subject to some uncertainty, see text.

	Pressure [kPa]	Time [days]	Chloride diffusion coefficient $D \cdot 10^{12} \text{ [m}^2\text{/s]}$
Great Belt Concrete	800	1	28
$w/c = 0,35$	100	23	4,0
$w/c = 0,35$	800	1	46
$w/c = 0,45$	100	23	7,3
$w/c = 0,45$	800	5	50*
$w/c = 0,55$	100	23	12
$w/c = 0,55$	800	5	38*

In Table 1 some values are marked with a '*'. These values are subject to some uncertainty. For the concretes with $w/c = 0.45/0.55$ chlorides were measured all the way through the specimens

at 800 kPa. This means that the chloride ingress from the two absorption surfaces has affected each other. The conditions for using the Error Function solution then haven't been met since the solution is build on the assumption that the concrete can be understood as a half infinite medium. Therefore it has been more difficult to fit the Error Function solution to the experimental data for the concretes with $w/c = 0.45/0.55$.

The chloride diffusion coefficient describes how open a concrete is to chloride ingress. A low chloride diffusion coefficient corresponds to a low diffusion of chlorides through the concrete and reverse. From Table 1 it is seen that the chloride diffusion coefficient in general increases with an increase in w/c -ratio. This indicates that an increase in w/c -ratio causes a reduction in the resistance to chloride diffusion.

The experiment at 800 kPa was also conducted for concrete used at The Great Belt Tunnel in Denmark. As this concrete contains puzzolans the chloride diffusion coefficient is about half the value as for the concrete with the same w/c without puzzolans. However it is important to note that the concrete specimens from The Great Belt Tunnel has a maturity of approximately 15 years which of course influence the pore structure and the chloride ingress in the concrete.

If the chloride diffusion coefficients at 100 kPa and 800 kPa are compared it is seen that for concrete with $w/c = 0.35$ the chloride diffusion coefficient at 800 kPa is 12 times greater as at 100 kPa. For the concretes with $w/c = 0.45$ and $w/c = 0.55$ the chloride diffusion coefficient is increased 7 and 3 times, respectively. That the increase isn't as pronounced as for the concrete with $w/c = 0.35$ can be explained by the fact that the conditions for the Error Function solution haven't been met.

Despite the fact that there have been some uncertainties on the results, there is no doubt of the tendency that the results show. An increase in water pressure does clearly affect the chloride diffusion in concrete for both low and high w/c -ratios.

4. CONCLUSION

The chloride diffusion coefficient is a transport parameter, which is used when estimating the life time of concrete structures. The coefficient is according to our results increased with a factor up to 12 compared at water pressures of 800 kPa and 100 kPa. This means that the water pressure has a great influence on the chloride diffusion and thereby on the life length models which are to be used for concrete structures.

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